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An Update on C458 Al-Li for Cryotanks

by

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Major Tank Components

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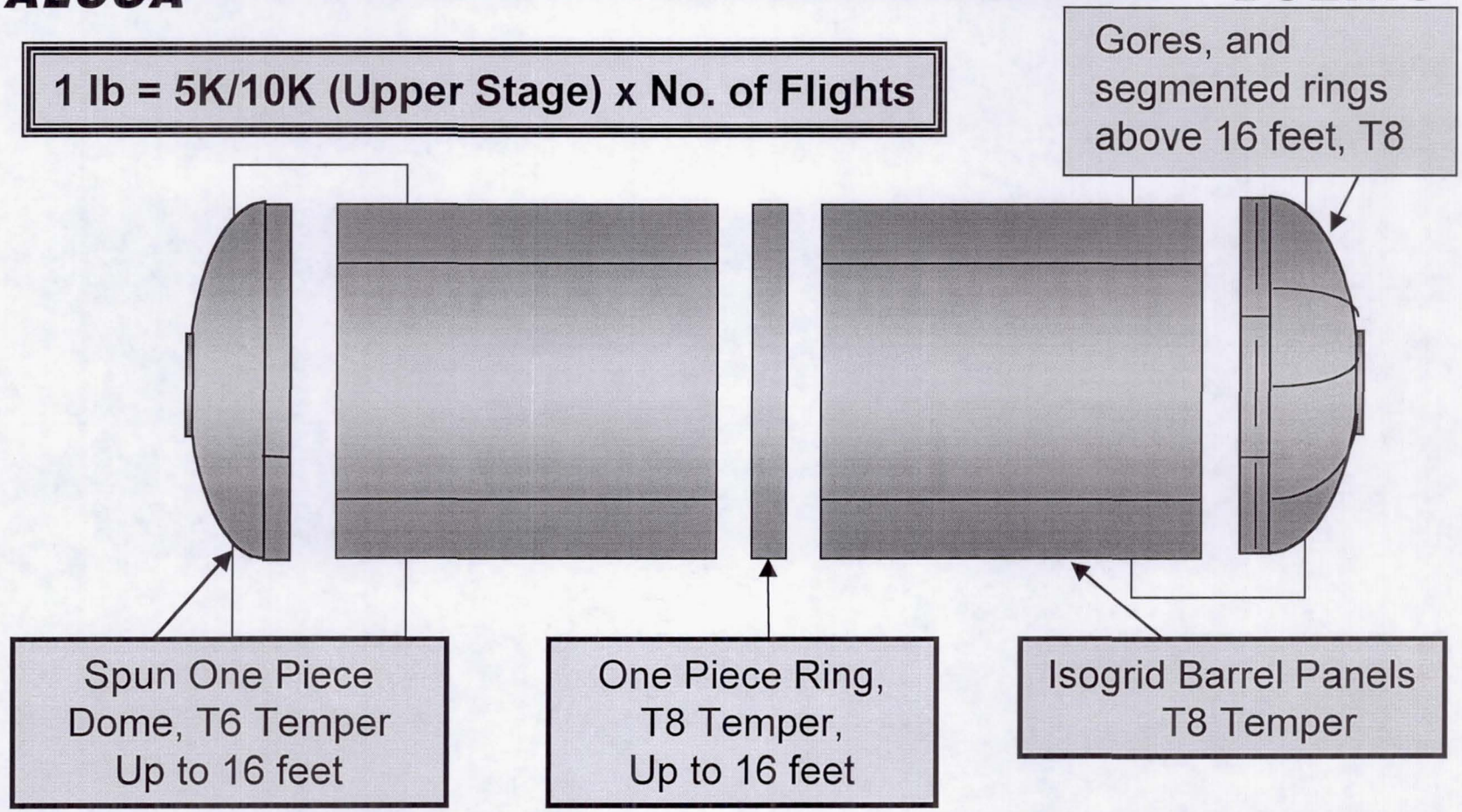
1 lb = 5K/10K (Upper Stage) x No. of Flights



For upper-stage expendable and reusable flight cryotanks, higher initial material cost acceptable

Achieving Design and Production Readiness

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- **Mill Practices**
  - Establish production C458 ingot casting capability (done)
  - Conduct DOE for plate to guarantee properties
- **Design**
  - Establish design databases for product forms
  - Establish approach to accommodate delaminations (in work)
  - Build and cycle a cryotank (planning in work)
- **Manufacturing**
  - Establish circumferential FSW (in work)
  - Sump seal welding
  - Fabricate domes without recrystallization (in work)
  - Establish aging cycles for cryotank (done)

 — Done

 — Partially funded in work

 — Currently not funded

History of C458 Ingot Casting Capability

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- When alloy was developed no effort was made to establish a production ingot casting capability
  - Two ingots rolled into plate 0.5, 0.75 and 1.8 in.
- As part of the SLI program, SLI and the AF funded an effort to establish production ingot casting capability
  - Eight ingots cast , five rolled into plate
  - 0.5 and 2.5 inch plate rolled representing three heat lots

Alcoa production target yield achieved

C458 Plate Properties

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- One-step aging established previously used for acceptance testing at mill
- Strength at t/2 and t/4 was measured in the L, LT and 45 degree orientations
- Unrecrystallized microstructure obtained
- Comparative T6 temper properties not available

Strengths similar to that obtained previously

Summary of Attained Properties

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	Initial AF Program		Data from SLI Program				
	Lot Release Test Results						
Temper practice	24Hs.@300F	24Hs.@300F	24Hs.@300F	24Hs.@300F	36Hs@300F	36Hs/300F	24Hs@320F
Property/Orientation	T8	T8	T8	T8	T8	T8	T6
Thickness (in)	1.8"	0.50"	2.4"	2.4"	2.4"	2.4"	0.5"
	UnRx t/2	UnRx t/2	UnRx t/2	UnRx t/4	UnRxt/2	UnRxt/4	UnRxt/2
UTS (Ksi) L	76	76	76	71	81	76	67
LT	75	78	75	73	79	75	66
45	73	72	69	70	73	75	60
ST	74						
TYS (Ksi) L	71	71	71	63	77	72	51
LT	65	68	68	68	72	66	50
45	61	60	61	61	64	66	43
ST	57						
Elongation (%) L	7.4	10.7	8	10	7	8	15
LT	7.4	8.9	8	8	8	9	15
45	8.8	12.8	10	11	9	9	14
ST	4.6						

Additional Work at Primary Producer

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Cryotank Product	Delivered to Part Manuf.	Work Required
Domes	O or F Temper Plate	Plate Acceptance Specification
Cylinder	O or T3 Temper	DOE and Procurement Spec
Rings	Ingot	Ingot Acceptance Specification

- *DOE needed to ensure plate properties*
- *Sufficient mill work done to provide material for one piece domes and one-piece rings*

Prioritizing Design Database Development

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Components	Temper	Probable Design Sizing Parameter			
		Expendable (Upper Stage)		Re-usable (booster)	
		Wt %	Property	Wt %	Property
Barrel Panels	T8	10%	E_c	69%	E_c
Aft Lox Dome	T6	39%	F_{tu}	3.5%	F_{tu}
Other 3 Domes	T6	45%	Handling	4.1%	Life
Weld Lands	TBD	6%	F_{tu}	6%	F_{tu}
Rings	T8	-----	F_{tu}, E	16%	F_{tu}, E

Creating a design database for cryotank sizing can be readily prioritized

Typical Plate (L) Property Comparison

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Alloy	TUS ksi	TYS ksi	e%	Aging Cycle
C458-T8	77	67	10	1 step, 24 hr at 300°F
C458-T8	81	72	10	2 step, 48 hr at 205°F + 24 hr at 300°F
C458-T6	77	62	7	2 step, 12 hr at 250°F + 24 hr at 300°F
C458-T6	72	52	11	2 step, 96 hr at 175°F + 24 hr at 325°F
2219-T87	69	56	10	Standard

Tailor aging cycles for each component

Dynamic Modulus At Cryo

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Static Modulus

Alloy	Temp	Longitudinal x 10^6 psi		45°x 10^6 psi	
		Et	Ec	Et	Ec
2219	RT	10.5	10.8	10.5	10.8
C458	RT	11.6	11.9	11.1	11.5

*Numbers in red are estimates

Dynamic Modulus (L)

Alloy	Temp	E_d (C)
C458	RT	11.5
C458	-320°F	12.8

Dynamic modulus excellent for determining change in modulus as a function of temperature

Life/Delaminations

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Thick.,	Thick. inch	Cycles to Leak*	Cycles to Failure
C458-T8	0.150	7,750	Not tested
C458-T8	0.250	11,500	12,761
2219-T87	0.145	2,500	------

*Stressed to $F_{tu}/1.5$

- Delaminations do occur and their role in design being studied under an AF funded effort by NASA

Fatigue life (K_{Ie}) excellent with a minimum penetrant detectable crack

Crack Path Changes

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Two photos showing crack deviation

- *Fracture mechanics models don't address behavior*
- *More reliance required on testing*

Joint AF/Alcoa/LMU/ Boeing Work in Progress

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- **Circumferential FSW**
  - Demonstrate ability to join 8-ft. diameter rings of C458-T8 made from rolled 0.5-inch thick plate
    - Determine tensile properties
- **Dome Spinning – four phase program, first phase being addressed in FY 2003**
  - Phase 1: Establish spin temperatures and associated recovery anneals required – subscale. Also optimize T6 strengths through modified aging cycles
  - Phase 2: Spin full thickness cone, subscale diameter to verify what was learned in Step 1
  - Phase 3: Spin subscale dome using same processing steps as would be used for a full scale dome
  - Phase 4: Spin 2 full scale domes. Verify process. Final machine and determine dimensional changes

Path to production readiness being addressed

Circumferential FSW

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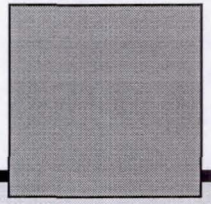
Photo of CFSW Equipment at Boeing HB



8-ft. sufficiently large to provide confidence in proceeding with larger sizes

C458 Dome Fabrication

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Photo of C458 cone spun from plate

- *1.8-inch thick C458 softer than 2219 at temp.*
- *Geometry can be readily produced*

Conclusions Relative to C458 Cryotanks

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- C458 fracture behavior different than conventional Al alloys - more reliance on test required
  - Conduct tank test
- Expendable (also path finder for reusable)
  - Dome development activities need to be completed as most of the weight is in the domes
- Reusable
  - Develop understanding of delamination behavior
  - Demonstration – build and cyclic test a tank to develop confidence in the technical community on the use of C458